3.2 Particles and Radiation: 30-minute Pack

AQA 7408 · Calculator allowed · about 30 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 This question concerns three radioactive decay processes. Use nuclide notation $^{A}_{Z}X$ throughout, represent the β-minus particle as $^{0}_{-1}e$ and the positron as $^{0}_{1}e$, and write neutrinos and antineutrinos in words.

(a) Americium-241 ($^{241}_{95}Am$), used in household smoke detectors, decays by α emission. Write a balanced nuclear equation for this decay, giving the correct nucleon number and proton number for the daughter nuclide. **(2)**

(b) Potassium-40 ($^{40}_{19}K$), present naturally in rocks and used in potassium-argon dating, can decay by β-minus emission. Write a balanced nuclear equation for this decay, including correct notation for the β particle and the antineutrino produced, and give the correct nucleon number and proton number for the daughter nuclide. **(2)**

(c) Sodium-22 ($^{22}_{11}Na$), used to calibrate medical PET scanners, decays by β-plus emission (positron emission). Write a balanced nuclear equation for this decay, including correct notation for the positron and the neutrino produced, and give the correct nucleon number and proton number for the daughter nuclide. **(2)**

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(d) Beta-plus decay occurs when a proton inside the nucleus is transformed into a neutron. Describe what happens to the quark content of the proton during this process, and name the exchange particle involved. **(3)**

(Total for Question 1 is 9 marks)

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2 In the α-scattering experiment, a narrow beam of α particles was directed at a thin gold foil in an evacuated chamber, and the number of α particles scattered was measured at various angles using a rotatable detector screen.

(a) Explain how the results of the α-scattering experiment led scientists to reject the 'plum pudding' model of the atom in favour of the nuclear model. **(6)**

(b) The radius of a gold nucleus is of order 10^{-14} m, while the radius of a gold atom is of order 10^{-10} m. Calculate the ratio of the atomic radius to the nuclear radius. **(2)**

(Total for Question 2 is 8 marks)

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3 A hospital uses the medical tracer isotope technetium-99m, which has a half-life of 6.01 hours. At 09:00 the hospital receives a sealed sample with an initial activity of 640 MBq.

(a) Calculate the decay constant, λ, of technetium-99m in s^{-1}. **(2)**

(b) Calculate the activity of the sample at 15:00 on the same day, using $A = A0\ e^{-\lambda t}$. **(3)**

(c) The sample must not be used clinically once its activity falls below 15 MBq. Calculate the time, in hours after 09:00, at which the activity of the sample first falls below 15 MBq. **(3)**

(Total for Question 3 is 8 marks)

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Mark scheme · 3.2 Particles and Radiation: 30-minute Pack

Question 1

(a) identify daughter nuclide with A = 237, Z = 93 (neptunium) **M1**

(a) correct full equation: ^241_95 Am -> ^237_93 Np + ^4_2 He, cao **A1**

(a) Answer: ^241_95 Am -> ^237_93 Np + ^4_2 He

(b) identify daughter nuclide with A = 40, Z = 20 (calcium) **M1**

(b) correct full equation: ^40_19 K -> ^40_20 Ca + ^0_-1 e + electron antineutrino, cao **A1**

(b) Answer: ^40_19 K -> ^40_20 Ca + ^0_-1 e + electron antineutrino

(c) identify daughter nuclide with A = 22, Z = 10 (neon) **M1**

(c) correct full equation: ^22_11 Na -> ^22_10 Ne + ^0_1 e + electron neutrino, cao **A1**

(c) Answer: ^22_11 Na -> ^22_10 Ne + ^0_1 e + electron neutrino

(d) an up quark (u) within the proton (quark composition uud) changes into a down quark (d), so the proton (uud) becomes a neutron (udd) **M1**

(d) this change occurs via the weak interaction, with the emission of a virtual W+ boson (the exchange particle for this process) **M1**

(d) the virtual W+ boson then decays into a positron and an electron neutrino, the particles emitted from the nucleus **A1**

(d) Answer: An up quark changes to a down quark (uud to udd), via the weak interaction, emitting a virtual W+ boson which decays to a positron and an electron neutrino

Question 2

(a) **L3** A full, coherent explanation linking all three key observations (most alpha particles undeflected, some deflected through small angles, a very small fraction deflected through large angles including back-scattering) to specific features of the nuclear model (mostly empty space, a small region of concentrated positive charge, and a large concentrated positive charge/mass), with a clear comparison to why the plum pudding model could not account for the large-angle scattering. **5-6**

(a) **L2** The answer describes at least two of the key observations and links them to features of the nuclear model, but the explanation is incomplete or does not fully explain why the plum pudding model is inconsistent with the large-angle scattering. **3-4**

(a) **L1** A basic statement that most particles passed through with few deflections, with little or no explanation of what this implies about atomic structure. **1-2**

(a) **L0** No relevant content, or the answer does not relate to the question. **0**

(a) Indicative content:

- Most alpha particles passed straight through the foil with little or no deflection, showing that most of the atom is empty space.
- A small proportion of alpha particles were deflected through small angles, showing that there is a concentration of positive charge somewhere in the atom that repels the (positive) alpha particles.
- A very small fraction (about 1 in 8000) of alpha particles were deflected through angles greater than 90 degrees, with some rebounding almost back the way they came.
- This large-angle scattering could only happen if the alpha particles were repelled by an extremely concentrated positive charge and mass, far smaller than the size of the whole atom - the nucleus.
- The plum pudding model, in which positive charge is spread thinly throughout the whole atom, predicts only small deflections everywhere and cannot account for any large-angle scattering, since the electric field from such spread-out charge is never strong enough at any point to reverse an alpha particle's direction.
- The observation of large-angle scattering therefore directly contradicted the plum pudding model and supported a model with a small, dense, positively charged nucleus at the centre of a mostly empty atom.

(a) Answer: The undeflected majority showed the atom is mostly empty space; the small-angle deflections showed a concentration of positive charge; the rare large-angle deflections showed that charge and mass are concentrated in a tiny nucleus, which the plum pudding model (with charge spread throughout the atom) could not explain.

(b) ratio = 10^{-10} / 10^{-14} **M1**

(b) 1 x 10^{4} (i.e. the atom is about 10000 times larger than its nucleus) cao **A1**

(b) Answer: About 1 x 10^{4} (the atom is roughly 10000 times larger than its nucleus).

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Question 3

(a) convert half-life to seconds (6.01 x 3600 = 21636 s) and substitute into $\lambda = \ln 2 / \text{half-life}$ **M1**

(a) $3.20 \times 10^{-5}\ s^{-1}$, cao **A1**

(a) Answer: $3.20 \times 10^{-5}\ s^{-1}$

(b) identify t = 6 hours = 21600 s **M1**

(b) substitute $A = 640 \times e^{-3.20 \times 10^{-5} \times 21600}$, ft from (a) **M1**

(b) 320 MBq (accept 315-325 MBq), awrt **A1**

(b) Answer: 320 MBq

(c) rearrange $A = A0\ e^{-\lambda t}$ to give $t = \ln(A0/A) / \lambda$ **M1**

(c) substitute $t = \ln(640/15) / (3.20 \times 10^{-5})$ in seconds, ft from (a) **M1**

(c) 32.5 hours (accept 32-33 hours), awrt **A1**

(c) Answer: 32.5 hours

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